METHOD AND APPARATUS FOR PERFORMING LINEARIZATION IN A QUADRATURE TRANSMITTER

Field of the Invention

5

This invention relates to a radio transmitter in a
wireless communication unit. The invention is applicable
to, but not limited to, a training mechanism to configure
a radio transmitter that employs a linearisation

10   technique to provide a stable, linear output.

Background of the Invention

Wireless communication systems, for example cellular

15   telephony or private mobile radio communication systems,
typically provide for radio telecommunication links to be
arranged between a plurality of base transceiver stations
(BTSs) and a plurality of subscriber units, often termed
mobile stations (MSs). The term mobile station generally

20   includes both hand-portable and vehicular mounted radio
units. Radio frequency (RF) transmitters are located in
both BTSs and MSs in order to facilitate wireless
communication between the communication units.

25   In the field of this invention, it is known that
continuing pressure on the limited radio spectrum
available for radio communication systems is focusing
attention on the development of spectrally efficient
linear modulation schemes. By using spectrally efficient

30   linear modulation schemes, more communication units are
able to share the allocated spectrum within a defined
geographical coverage area (communication cell). An
example of a digital mobile radio system that uses a

- 2 -

linear modulation method, such as n/4 digital quaternary
phase shift keying (DQPSK), is the TErrestrial Trunked
RAdio (TETRA) system, developed by the European
Telecommunications Standards Institute (ETSI).

5

Since the envelopes of these linear modulation schemes
fluctuate, intermodulation products can be generated in
the non-linear radio frequency power amplifier(s).
Specifically in the digital mobile radio (PMR)

10   environment, restrictions on out-of-band emissions are.
severe (to the order of -60dBc to -70dBc relative to the
power in adjacent frequency channels). Hence, linear
modulation schemes used in this scenario require highly
linear transmitters.

15

The actual level of linearity needed to meet particular
out-of-band emission limits, is a function of many
parameters, of which the most critical parameters are
modulation type and bit rate. Quantum processes within a

20   typical radio frequency (RF) amplifying device are non-
linear by nature. Only a straight line may approximate
the transfer function of the amplifying device when a
small portion of the consumed direct current (DC) power
is transformed into radio frequency (RF) power, i.e. as

25   in an ideal linear amplifier case. This mode of
operation provides a low efficiency of DC to RF power
conversion, which is unacceptable for portable units.

The emphasis in portable PMR equipment is to increase

30   battery life. Hence, it is imperative to maximise the
operating efficiencies of the amplifiers used. To
achieve both linearity and efficiency, so called
linearisation techniques are used to improve the

- 3 -

linearity performance of the more efficient classes of
amplifier, for example class AB, B or C amplifiers. One
such linearisation technique, often used in designing
linear transmitters, is Cartesian Feedback. This is a
5   'closed loop' negative feedback technique, which sums the
baseband feedback signal in its digital 'I' and 'Q'
formats with the corresponding generated 'I' and 'Q'
input signals in the forward path. This 'closed loop' I-
Q combination is performed prior to amplifying and up
10   converting the input signal to its required output
frequency and power level. The linearising of the power
amplifier output requires the accurate setting of the
phase and amplitude of a feedback signal.

15   Details of the operation of such a lineariser is
described in the paper "Transmitter Linearisation using
Cartesian Feedback for Linear TDMA Modulation" by M
Johansson and T Mattsson 1991 IEEE.

20   The lineariser circuit optimises the performance of the
transmitter, for example to comply with linearity or
output power specifications of the communication system,
or to optimise the operating efficiency of the
transmitter power amplifier. Operational parameters of
25   the transmitter are adjusted to optimise the transmitter
performance and include as an example, one or more of the
following: amplifier bias voltage level, input power
level, phase shift of the signal around the feedback
loop. Such adjustments are performed by say, a
30   microprocessor. Due to the sensitivity of such
transmitter circuits, a range of control and adjustment
circuits and/or components are needed so that a linear

- 4 -

and stable output signal can be achieved under all
operating circumstances.

5   All linearisation techniques require a finite amount of
time in which to linearise the performance of a given
amplifying device. The 'linearisation' of the amplifying
device is often achieved by initially applying a training
sequence to the lineariser circuit and the amplifying
device in order to determine the levels of phase and gain
10   distortion introduced by the linearisation loop and the
amplifying device. Once the phase and gain distortion
levels have been determined, they can be compensated for,
generally by adjusting feedback components/parameters.

15   To accommodate for such linearisation requirements,
communication systems typically allocate specific
training periods for individual users to train their
transmitters. The TErrestrial Trunked RAdio (TETRA)
standard includes a time frame, termed a Common
20   Linearisation Channel (CLCH) as is described in UK Patent
Application No. 9222922.8, to provide a full-training
period approximately once every second. The CLCH frame
allows a radio to 'train' prior to gaining access to the
system. However, a radio having to wait up to one second
25   before training and then accessing the system is
undesirable. To assist this significant delay in call
set-up times, and also provide an additional period for
fine tuning a radio's output characteristics, due to
changes in temperature, supply voltage or frequency of
30   operation, a reduced training sequence has been inserted
at the beginning of each TETRA traffic time slot for the
radio allocated that slot to perform a minimal amount of

- 5 -

training or fine tuning. This period may be used for
phase training.

5   An example of such a training sequence is described in US
       Patent No. 5,066,923 of Motorola Inc., which describes a
       training scheme where the phase of the amplifier is
       adjusted in an 'open-loop' mode and the gain of the
       amplifier is adjusted when the loop is closed.

10   During phase training, the Cartesian feedback loop is
       configured to be 'open loop', i.e. a switch is used to
       prevent the fed-back signal from being combined with the
       signal routed through the transmitter circuit. In this
       regard, in a phase training mode of operation, a positive
15   signal is applied to the I-channel input. The phase
       shift around the loop is measured and, in response to the
       measured I-channel phase shift, the phase around the loop
       on both the 'I'-channel and the 'Q'-channel is adjusted
       by a phase shifter.

20

       FIG. 1 illustrates a phase diagram 100 with a perfect I/Q
       quadrature balance, i.e. a 90-degree phase difference
       between the I-channel 120 and the Q-channel 110. The
       Cartesian loop is opened and a positive baseband signal
25   applied to the input of the 'I'-channel. Phase training
       control circuitry monitors the signal before switch 426
       on the Q channel - indicated as Vfq 455. A successive
       approximation register (SAR) phase training algorithm
       controls the phase shifter and minimises the Vfq voltage.
30   At the end of the SAR algorithm, phase training corrects
       the loop phase by an angle β. A voltage value prior to
       the switch on the Q channel is then reduced close to
       zero. The same process is repeated for a negative

- 6 -

baseband signal input to the I-channel. The calculated
results from both the positive and negative training
applied to the I-channel are averaged and used to adjust
the phase around both the I-channel loop and the Q-
5   channel loop.

The inventors of the present invention have recognised
and appreciated that, in practice, the perfect I-Q 90-
degree relationship is rarely achieved. This imbalance
10   results from the various component tolerances within the
respective 'I' and 'Q' loops. An unbalanced phase
relationship 200 is illustrated in FIG. 2. Here, Q' is
the actual loop's quadrature axis 210. The Q' axis 210
deviates from the ideal Q axis 110 by α degrees 220.
15   Again Vfq is minimized using Q' axis 210 as quadrature.
From FIG. 2, we can see that instead of correcting the
loop phase by β degrees 230, the phase training process
has corrected the loop phase by $\beta-\alpha$ degrees 240. This
means that phase training provides a result that is
20   inaccurate by α degrees 220. With reference to FIG. 4,
the I/Q imbalance α may be in the forward 436 or feedback
422 I/Q generator. For example, the feedback I/Q
generator 422 may shift the LO phase by 90-α degrees,
instead of an ideal 90 degrees.
25

The inventors of the present invention have identified
that any quadrature imbalance in the generation of
linearised signals during the training sequence of a
Cartesian loop transmitter may cause significant phase
30   training errors. Accurate phase training is a critical
stage in the linearisation of such transmitter circuits,

- 7 -

as the phase accuracy has a substantial effect on loop
stability and wideband noise.

Thus, there currently exists a need to provide an
5 improved transmitter circuit, and in particular a
mechanism for improving phase training accuracy, wherein
the abovementioned disadvantages may be alleviated.

Statement of Invention
10

In accordance with a first aspect of the present
invention, there is provided a wireless communication
unit. The wireless communication unit comprises a
linearised transmitter having a forward path, a power
15 amplifier and a feedback loop, operably coupled to the
power amplifier and the forward path. The feedback loop
comprises a loop adjustment function. The forward path
and feedback loop comprise quadrature circuits. A
processor applies a first training signal to a first
20 quadrature circuit loop for routing through the forward
path, power amplifier and feedback path to determine at
least one first parameter setting of the loop adjustment
function. The processor additionally applies a second
training signal to a second quadrature circuit loop to
25 determine at least a second parameter setting of the loop
adjustment function.

Preferably, the first training signal and the second
training signal have substantially the same signal
30 parameters, for example where they are phase training
signals. In this regard, the loop adjustment function is
a phase shifter for adjusting a phase shift in the first
and second quadrature circuit loops. A phase calculation

- 8 -

function, operably coupled to the phase shifter,
calculates a phase shift in each of the first and second
quadrature circuit loops, thereby determining an
imbalance therebetween.

5

In this manner, by applying a training signal to both
quadrature loops, any I/Q imbalance in the respective
loops will not influence the loop phase that will be
calculated using the inventive concepts described herein.

10

In accordance with a second aspect of the present
invention, a radio frequency transmitter integrated
circuit is provided, as claimed in Claim 9.

15 In accordance with a third aspect of the present
invention, a method of training a linearised transmitter
is provided, as claimed in Claim 10.

In accordance with a fourth aspect of the present
20 invention, a storage medium is provided, as claimed in
Claim 12.

Further aspects of the invention are provided in the
dependent claims.

25

Brief Description of the Drawings

FIG. 1 shows a phase diagram of an ideal I-Q relationship
in a feedback loop of a linear transmitter arrangement;
30 and

- 9 -

FIG. 2 shows a phase diagram of an unbalanced I-Q relationship in a feedback loop of a linear transmitter arrangement.

.5   Exemplary embodiments of the present invention will now be described, with reference to the accompanying drawings, in which:

FIG. 3 illustrates a block diagram of a wireless
10   communication unit adapted to support the various inventive concepts of a preferred embodiment of the present invention;

FIG. 4 illustrates a block diagram of a linearised
15   transmitter topology adapted in accordance with the preferred embodiment of the present invention;

FIG. 5 illustrates a flowchart of a linearisation · training process in accordance with the preferred
20   embodiment of the present invention; and

FIG. 6 illustrates a phase diagram of an unbalanced I-Q relationship modified in a feedback loop of a linear transmitter arrangement according to the preferred
25   embodiment of the present invention.

Description of Preferred Embodiments

Referring now to FIG. 3, a block diagram of a wireless
30   communication unit 300 adapted to support the inventive concepts of the preferred embodiments of the present invention, is illustrated. For the sake of clarity, the wireless communication unit 300 is shown as divided· into

- 10 -

two distinct portions - a receiver chain 305 and a
transmitter chain 325.

The wireless communication unit 300 contains an antenna
5   302. The antenna 302 is preferably coupled to an antenna
switch 304 that provides signal control of radio
frequency (RF) signals in the wireless communication unit
300, as well as isolation, between the receiver chain 305
and transmitter chain 325. Clearly, the antenna switch
10   304 could be replaced with a duplex filter, for frequency
duplex communication units as known to those skilled in
the art.

For completeness, the receiver 305 of the wireless
15   communication unit 300 will be briefly described. The
receiver 305 includes a receiver front-end circuitry 306
(effectively providing reception, filtering and
intermediate or base-band frequency conversion). The
front-end circuit 306 is serially coupled to a signal
20   processing function (generally realised by at least one
digital signal processor (DSP)) 308. A controller 314 is
operably coupled to the front-end circuitry 306 so that
the receiver can calculate receive bit-error-rate (BER)
or frame-error-rate (FER) or similar link-quality
25   measurement data from recovered information via a
received signal strength indication (RSSI) 312 function.
The RSSI 312 function is operably coupled to the front-
end circuit 306. A memory device 316 stores a wide array
of data, such as decoding/encoding functions and the
30   like, as well as amplitude and phase settings to ensure a
linear and stable output. A timer 318 is operably
coupled to the controller 314 to control the timing of

- 11 -

operations, namely the transmission or reception of time-
dependent signals.

As regards the transmit chain 325, this essentially
5 includes a processor 328, lineariser circuitry (including
transmitter/ modulation circuitry) 322 and an up-
converter/power amplifier 324. The processor 328,
lineariser circuitry 322 and the up-converter/power
amplifier 324 are operationally responsive to the
10 controller 314, with an output from the power amplifier
324 coupled to the antenna switch 304. A feedback
circuit includes a down-converter 332, which forms
together with the lineariser circuitry 322 power
amplifier 324 and directional coupler 342 a real-time
15 Cartesian feedback loop to ensure a linear, stable
transmitter output.

Prior to transmitting real data, the linearised
transmitter of the preferred employs a training
20 algorithm, to determine appropriate gain and phase
adjustment parameters to ensure a stable, linear output.
Notably, the preferred embodiment of the present
invention proposes a mechanism that improves an accuracy
of the phase training, for example utilising the phase
25 training algorithm described in US Patent No. 5,066,923
of Motorola Inc., which is incorporated herein by
reference. The proposed mechanism enables I/Q imbalances
within the loop to be compensated for.

30 Although the preferred embodiment of the present
invention is described with reference to phase training,
it is envisaged that the inventive concepts are equally
applicable to any other training signals that can be

- 12 -

routed around the respective quadrature loops to identify
imbalances therebetween, for example using amplitude
training signals.

5   FIG. 4 shows a more detailed Cartesian loop configuration
     400, adapted to support the preferred embodiment of the
     present invention. The configuration is described in the
     context of a phase training process, but clearly the same
     configuration is used when transmitting real data.

10

     A phase training signal, for example a sine wave, is
     input to the I channel 402. The phase training signal is
     not combined with any other signal in summing junction
     404, as the circuit has been arranged for open-loop

15   operation by controlling switches 424 and 426. The input
     signal is then input to a gain and low-pass filter block
     406 where it is amplified and filtered. The amplified
     input signal is then up-converted by mixing it with a
     signal from local oscillator 440 in mixer 408. The up-

20   converted signal is then routed to the RF amplifier chain
     412, where a portion of the amplified RF signal is fed
     back via directional coupler 414.

     The fed back signal is routed to down-conversion mixer

25   418, where it is mixed with a phase-shifted 442 version
     of a signal from the local oscillator 440. The amount of
     phase shift is controlled by a phase calculation and
     adjustment function 460.

30   Notably, in accordance with the preferred embodiment of
     the present invention, a second phase training sequence
     is now applied to the 'Q' channel input 430. The phase
     training signal, preferably the same sine wave, is input

- 13 -

to the Q-channel. The phase training signal is not
combined with any other signal in summing junction 432,
as the circuit has been arranged for open-loop operation
by controlling switches 424 and 426. The 'Q' input
5   signal is then input to a gain and low-pass filter block
434 where it is amplified and filtered. The amplified
input signal is then up-converted by mixing it with a
ninety-degree 436 phase-shifted representation of a
signal from the local oscillator 440 in mixer 438. The
10   up-converted signal is then routed to the RF amplifier
chain 412, where a portion of the amplified RF signal is
fed back via directional coupler 414.

The fed back signal is routed to down-conversion mixer
15   420, where it is mixed with a phase-shifted 442 version
of the local oscillator signal. The phase-shifted
version of the local oscillator signal has been further
phase shifted by ninety-degrees 422 to account for the
ideal I-Q quadrature nature of the circuit. The amount
20   of phase shift is again controlled by the phase
calculation and loop adjustment function 460.

In this manner, the phase shift of both the I-channel
loop and the Q-channel loop are measured. Once the
25   respective phase-shifts have been calculated, they are
compensated for by appropriate adjustment of the phase-
shifter, under control of the phase calculation and loop
adjustment function 460.

30   It is envisaged that the aforementioned training
mechanism is preferably implemented using a signal
processor function. More generally, the inventive
concepts may be implemented in a wireless communication

- 14 -

unit in any suitable manner for example by re-programming
or adapting a processor in the wireless communication
unit. For example, a new processor may be added to a
conventional wireless communication unit, or
5   alternatively existing parts of a conventional wireless
communication unit may be adapted, for example by
reprogramming one or more processors therein. As such
the required adaptation may be implemented in the form of
processor-implementable instructions stored on a storage
10   medium, such as a floppy disk, hard disk, programmable
read-only memory (PROM), random access memory (RAM) or
any combination of these or other storage media.

In summary, the preferred phase training process is
15   illustrated in the flowchart 500 of FIG. 5. The
linearisation training process commences in step 505. A
training signal, for example a phase training signal, is
input to a first quadrature loop, for example the 'I'
channel loop, in step 510. The phase shift exerted upon
20   the phase training signal around the 'I' channel loop is
then measured in step 515. A training signal, for
example the same phase training signal, is then input to
a second quadrature loop, for example the 'Q' channel
loop, in step 520. The phase shift exerted upon the
25   phase training signal around the 'Q' channel loop is then
measured in step 520. The respective phase shifts are
then calculated, in step 525. The phase shifts are then
compensated for by appropriate loop phase adjustments as
shown in step 530, to ensure the loop phase shift is
30   accurately controlled. The training process is then
complete as shown in step 535.

- 15 -

It is within the contemplation of the invention that the
phase shifter is adjusted after performing both the I-
channel phase training and the Q-channel phase training.
However, it is envisaged that in some circumstances the
5   phase-shifter may be adjusted after each individual phase
calculation has been made.

Thus, a primary distinguishing feature of the present
invention is the application of two training signals: a
10 first training sequence on the I-channel followed by a
second training sequence on the Q-channel. It is
envisaged that, for other linear transmitter topologies
or linearisation techniques, a training sequence, for
example phase training, on the 'I' channel and the 'Q'
15 channel may be performed simultaneously, rather than
successively. It is also envisaged that the use of two
training sequences: one for the I-channel and one for the
Q-channel, may comprise any combination or order of phase
training and/or amplitude training processes.
20

Referring now to FIG. 6, a phase diagram 600 of an
unbalanced I-Q relationship is illustrated, whereby the
phase has been modified in the feedback loop of the
linear transmitter arrangement according to the preferred
25 embodiment of the present invention. From FIG. 6 it can
be seen that when phase training is being performed on
the 'I' channel, the phase loop correction is $\beta-\alpha$ 240.

The second 'Q' channel loop phase is set to the phase
30 setting used before performing the I-channel phase
training. Now, when phase training is being performed on
the Q' channel, the correction is $\beta+\alpha$ 620.

- 16 -

From the above calculations it is possible to calculate the correct loop phase rotation needed β 230 even though there is a quadrature imbalance in the loop.

5   In summary, a new phase training method for elimination of errors in a Cartesian feedback loop linear transmitter has been described. The aforementioned inventive concepts provide a mechanism for compensating quadrature generator imbalances within the transmitter.

10   Advantageously, I-Q imbalance of both forward and feedback quadrature generator circuits are compensated for, both of which influence the phase adjustment calculation. Furthermore, as imbalances in the forward and backward quadrature generator circuits are

15   compensated for, it is possible to use less expensive components with a reduced tolerance and performance.

It is envisaged that integrated circuit manufacturers may utilise the inventive concepts hereinbefore described.

20   For example, it is envisaged that a radio frequency linearised transmitter integrated circuit (IC) containing the aforementioned transmitter circuit arrangement and method of training could be manufactured to be incorporated into a wireless communication unit.

25

Advantageously, the inventive concepts of the present invention provide a significant benefit to the manufacturers of linearised transmitter circuits, by compensating for quadrature imbalance by improving the

30   accuracy of a training process. For example, it is also within the contemplation of the invention that alternative linearisation techniques can benefit from the inventive concepts described herein. As an alternative

- 17 -

to using Cartesian feedback, a pre-distortion form of lineariser may be adapted to implement the preferred or alternative embodiments of the present invention. Y. Nagata described an example of a suitable pre-distortion
5   transmitter configuration in the 1989 IEEE paper titled "Linear Amplification Technique for Digital Mobile Communications".

However, it is within the contemplation of the invention
10   that the transmitter configuration of the preferred embodiment of the present invention may be applied to any wireless transmitter circuit.

Furthermore, it is within the contemplation of the
15   invention that the wireless communication unit employing the linearised transmitter may be any wireless communication device, such as a portable or mobile PMR radio, a mobile phone, a personal digital assistant, a wireless laptop computer, etc. It is also envisaged that
20   the inventive concepts described herein are not limited to use in subscriber equipment, but may also be utilised in other communication units such as base station equipment.

25   It will be understood that the wireless communication unit and linearised transmitter circuits, as described above, tend to provide at least one or more of the following advantages:
          (i) Improved phase training resulting in a more
30   stable output of the linearised transmitter circuit.
          (ii) The improved phase training result is not corrupted by the I/Q generators phase imbalance. Hence,

- 18 -

reduced tolerance components can be used in the loop I/Q generators.

(iii). Improved phase training results in a better wideband noise performance due to more accurate
5   phase training.

Whilst specific, and preferred, implementations of the present invention are described above, it is clear that one skilled in the art could readily apply further
10 variations and modifications of such inventive concepts.

Thus, a wireless communication unit with a linearised transmitter topology and improved training mechanism have been described that substantially addresses the problems
15 associated with known linearised transmitters.